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Transmittance Characteristics of U.S. Army Rotary-Wing Aircraft Transparencies

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This report documents a survey of the spectral and luminous transmittance characteristics of transparencies (windscreens) used in currently fielded U.S. Army rotary-wing aircraft. The survey was conducted in two phases. In the first phase, samples of windscreens from each aircraft type were evaluated in the laboratory for phototopic (day) and scotopic (night) luminous transmittance. The spectral transmittance of each sample also was measured. Based on laboratory measurements of unused samples, all windscreens met specifications. However, field measurements on windscreens showed consistent failure of luminous transmittance requirements. This loss of transmittance is attributed to haze resulting from exposure to environmental factors.

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Introduction

This report documents a survey of the spectral and luminous transmittance characteristics of transparencies (windscreens) used in currently fielded U.S. Army rotary-wing aircraft (AH-1 Cobra, AH-64 Apache, CH-47 Chinook, OH-6 Cayuse, OH-58A/C/D Kiowa, TH-67 Creek, UH-1 Iroquois, and UH-60 Black Hawk [Figures 1-10]). These characteristics are essential to addressing issues related to aviator and crewman visual performance. In addition, spectral transmittance characteristics impact the performance of helmet-mounted imaging systems, such as the AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS).

Previous investigations of the optical characteristics of U.S. Army rotary-wing aircraft transparencies (Chiou, 1975, 1976; Chiou, Park, and Moser, 1976; Crosley, 1968) may no longer be representative of currently fielded transparencies. Manufacturers of U.S. Army aircraft transparencies often change with each procurement contract. Appendix A provides a list of current manufacturers.

The survey was conducted in two phases. In the first phase, samples of windscreens from each aircraft type were evaluated in the laboratory for photopic (day) and scotopic (night) luminous transmittance. The spectral transmittance of each sample also was measured.

Installed transparencies are exposed continuously to the environment, collision with airborne particulate matter, and the abuses which often accompany aircraft maintenance. Therefore, to provide a more realistic assessment of transmittance values as experienced in the field, a second phase consisting of field measurements of photopic luminous transmittance for windscreens installed on aircraft on the flight line was conducted.

The laboratory measurements were taken on new (or not previously used) transparency samples. Due to limited availability of such transparencies, only a single sample of each forward windscreen could be obtained for each aircraft type. [An exception to this was the inability to obtain any front windscreens of the OH-6 or the right front windscreen for the UH-60.] Therefore, the data reported herein should be considered only representative of transparency performance. Field measurements (photopic transmittance only) were made on six aircraft per type.

Specifications and requirements

MIL-W-81752A(AS), "Military specification: Windshield systems, fixed wing aircraft, general specification for,"

Figure 1. The AH-1 Cobra.

Figure 2. The AH-64 Apache.

Figure 3. The CH-47D Chinook.

Figure 4. The OH-6 Cayuse.

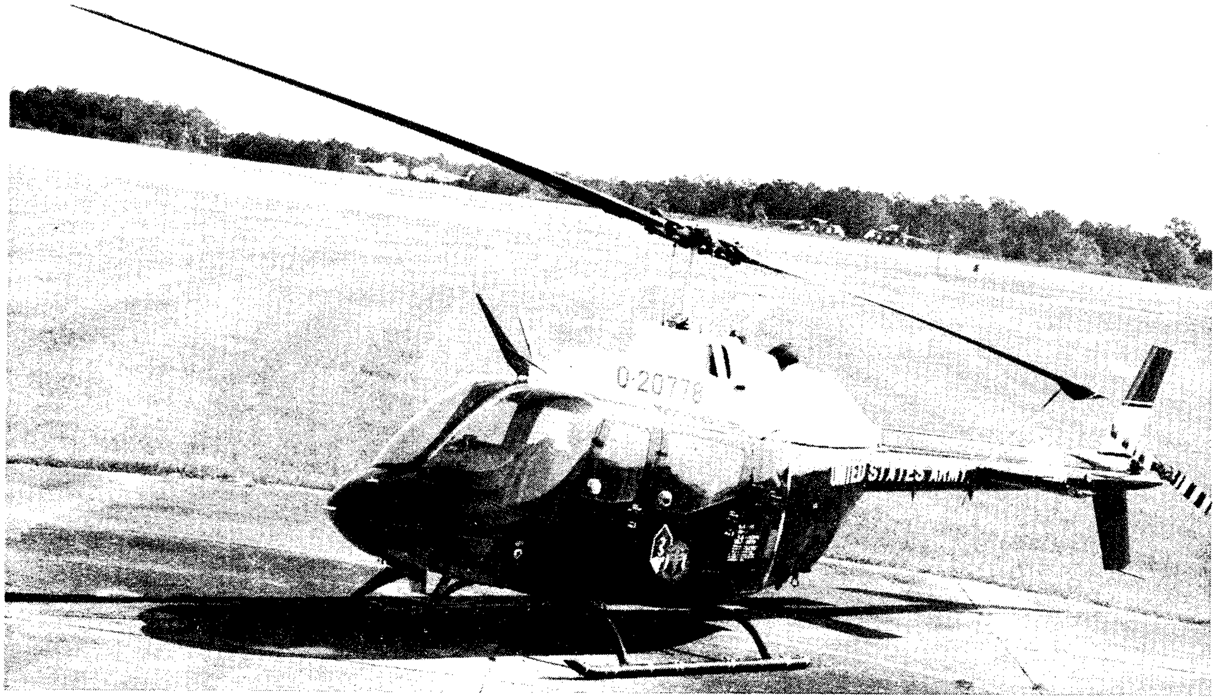

Figure 5. The OH-58A Kiowa.

Figure 6. The OH-58C Kiowa.

Figure 7. The OH-58D Kiowa.

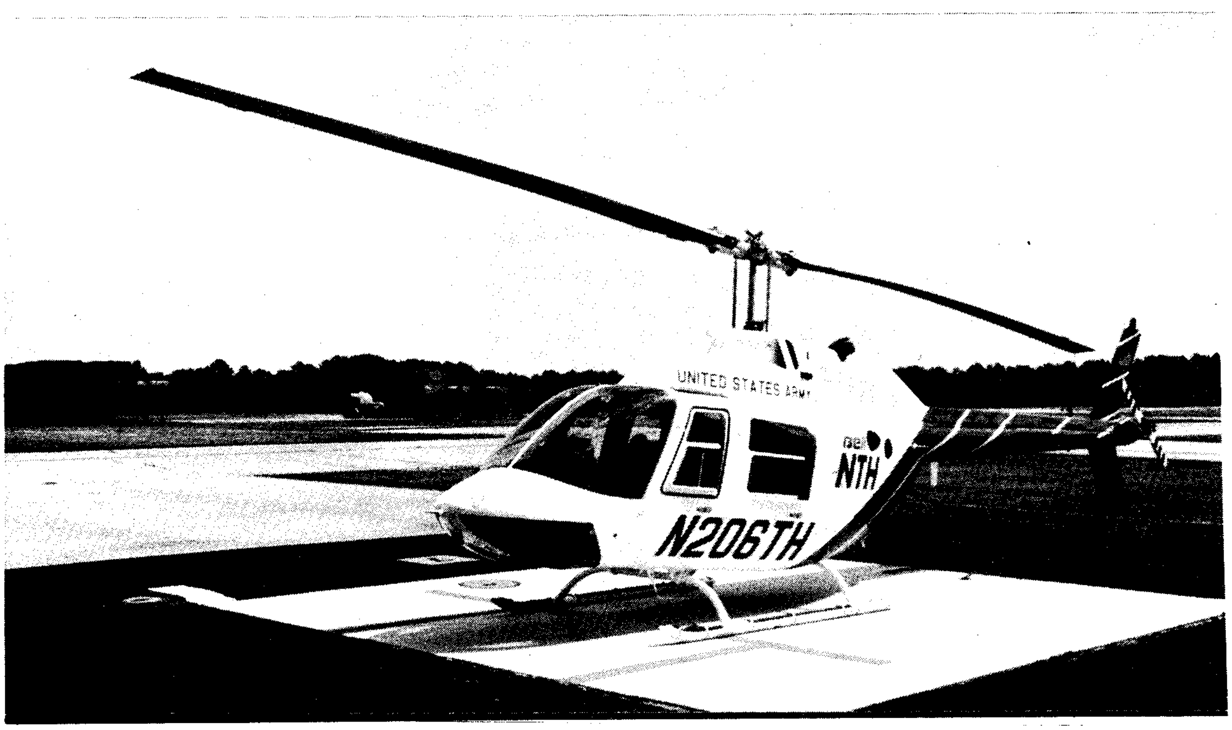

Figure 8. The TH-67 Creek.

Figure 9. The UH-1 Iroquois.

Figure 10. The UH-60 Black Hawk.

requires attack type aircraft to have an average luminous transmittance of not less than 80 percent when measured at normal angles of incidence to the surface. Other aircraft are required to have an average luminous transmittance of not less than 60 percent when measured at normal angles of incidence to the surface.

During day flights, pilotage and other external tasks are primarily accomplished by naked eye viewing through the windscreens and windows. However, current U.S. Army doctrine requires pilots and crewmen to perform missions successfully during periods of low illuminance, e.g., at night and in foul weather. To achieve acceptable performance under these conditions, devices based on the principle of image intensification are used in the cockpit and crew areas. The most prominent of these devices is the ANVIS. This night vision system has a spectral response of 450-950 nanometers (nm) with an enhanced sensitivity from 625-900 nm (MIL-L-85762A). Windscreens and windows must provide adequate spectral transmittance over this latter spectral range to optimize ANVIS performance.

MIL-W-81752A(AS) states the windshield shall be (ANVIS) compatible over the wavelength range of 600-900 nanometers.

Methodology

Spectral transmittance

Spectral transmittance data were obtained in a darkened laboratory using an EG&G Gamma Scientific* model C-9 spectral scanning system and a model RS-1 tungsten source. Spectroradiometric data were measured over the wavelength range of 350-950 nanometers in 5-nm steps for the reference tungsten source alone and for each transparency sample/source combination. The transmittance curves were obtained by performing a division, by wavelength, of the transparency/source combination data by the source data.

A sample of the left front windscreen was measured in each aircraft with side-by-side seating. A lower front windscreen sample was measured for the attack aircraft, which have tandem seating. In order to minimize scratching of the unused transparencies during measurement, the protective sheeting was removed from as small an area as possible. Therefore, measurements were taken at arbitrary and different points on each samples. [Note: This was not considered to be a relevant factor since an investigation of several samples showed a variation of less than 5 percent across the sample. A similar investigation

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*See Appendix B.

of the effect of slant (deviation from normal) also showed a variation of less than 5 percent.] Settings of 900 volts photomultiplier tube anode voltage and 1-degree aperture size on the collection optics were used.

Luminous transmittance

Photopic and scotopic luminous transmittance values were measured in a darkened laboratory using a Photo Research* model 1980A photometer and EG&G Gamma Scientific model RS-1 tungsten source. Following a prescribed warm-up period for the photometer and the reference lamp, luminous transmittance measurements were taken for each sample using the photopic and scotopic filters integral to the photometer. Each measurement consisted of reading the luminance of the reference lamp, placing the respective transparency sample normal to the optical path, and taking a second luminance reading. The transmittance was calculated by dividing the luminance value obtained of the sample/source combination by the value obtained of the source alone. Three readings were obtained for each sample. The mean of these three values was calculated and reported.

Field measurements

Field measurements of photopic transmittance values were acquired for six of each aircraft type on flight lines at U.S. Army airfields at Fort Rucker, Alabama. [Note: An exception was the OH-58C aircraft, where only four aircraft were measured.] Measurements were made using an EG&G Gamma RS-1 tungsten source powered by a field generator and a Minolta* 1-degree aperture luminance meter. Each measurement consisted of reading the luminance of the reference source alone and reading the reference source luminance from a position of the left seat for aircraft with side-by-side seating and from the front seat of aircraft with tandem seating. The transmittance was calculated by dividing the value obtained from the cockpit by the value of the source alone.

Data

Spectral transmittance

The transmittance curves for the windscreen sample are provided in Figures 11-18. The samples from AH-64 (except aft windscreen), CH-47, UH-1, and UH-60 aircraft were of glass composition. The AH-1, OH-58A/C/D, and TH-67 samples were of acrylic composition. All samples were of "clear" material except for the TH-67, which had a bluish tint.

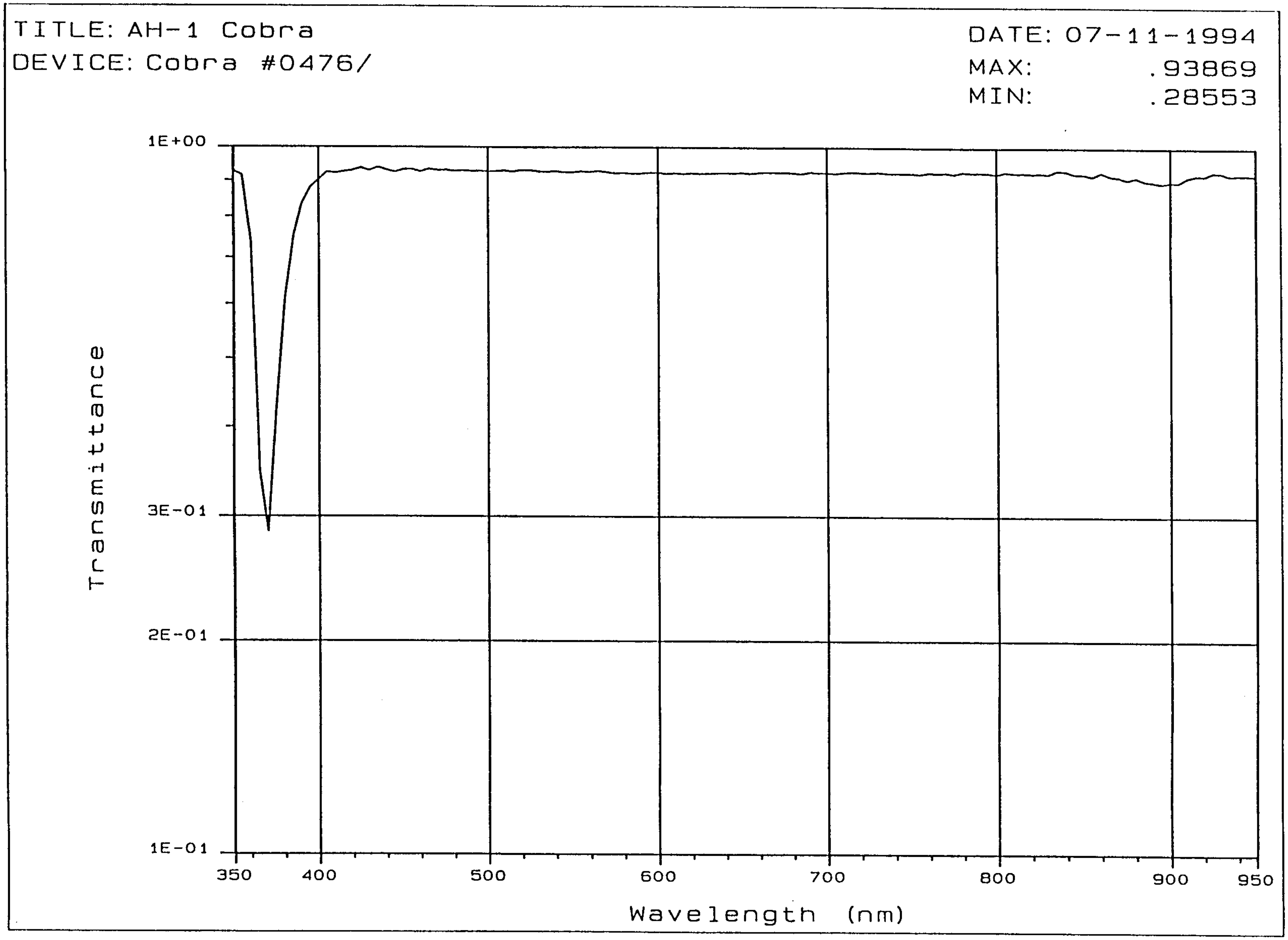

Figure 11. Spectral transmittance curve for AH-1 Cobra.

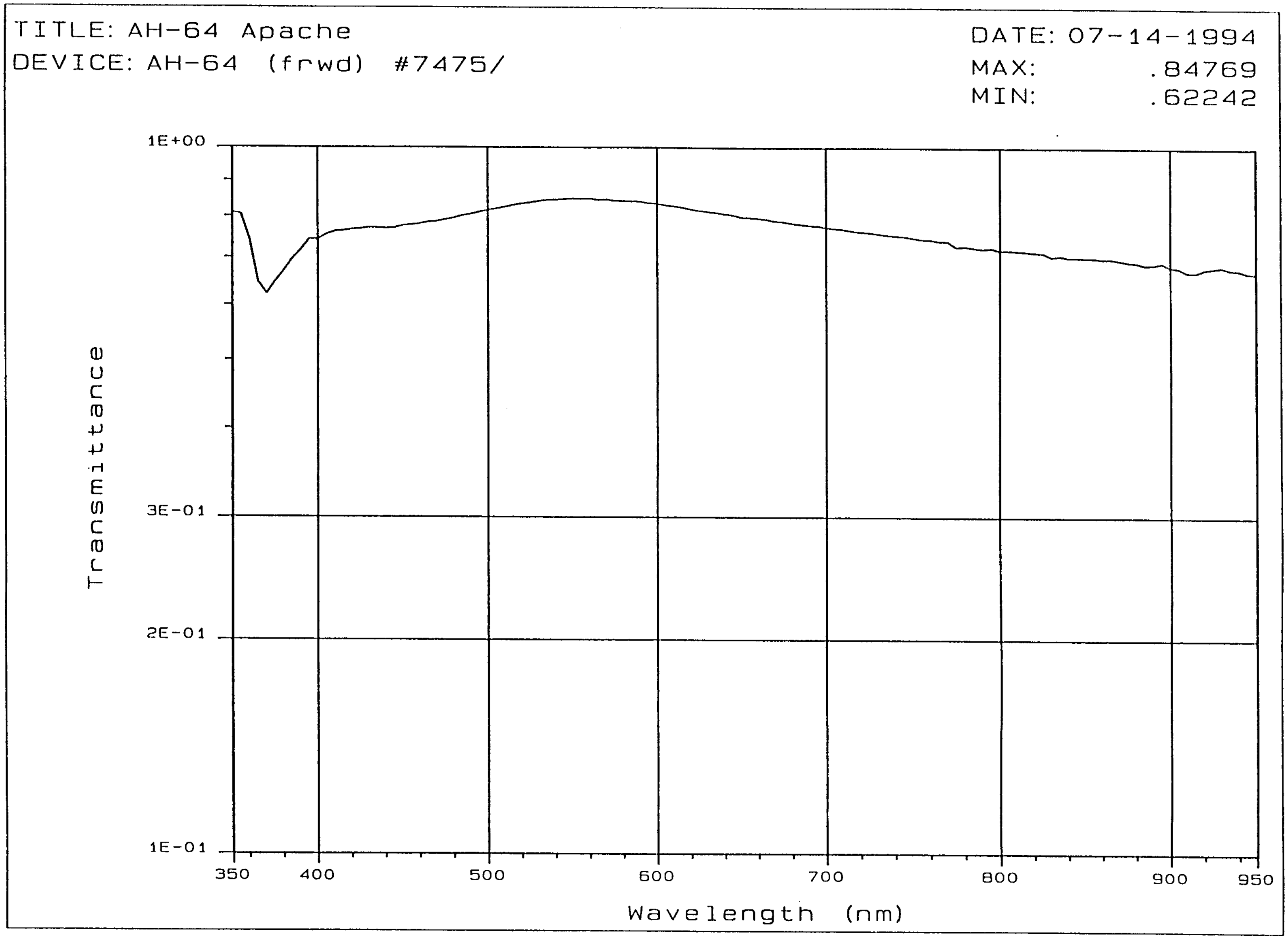

Figure 12. Spectral transmittance curve for AH-64 Apache.

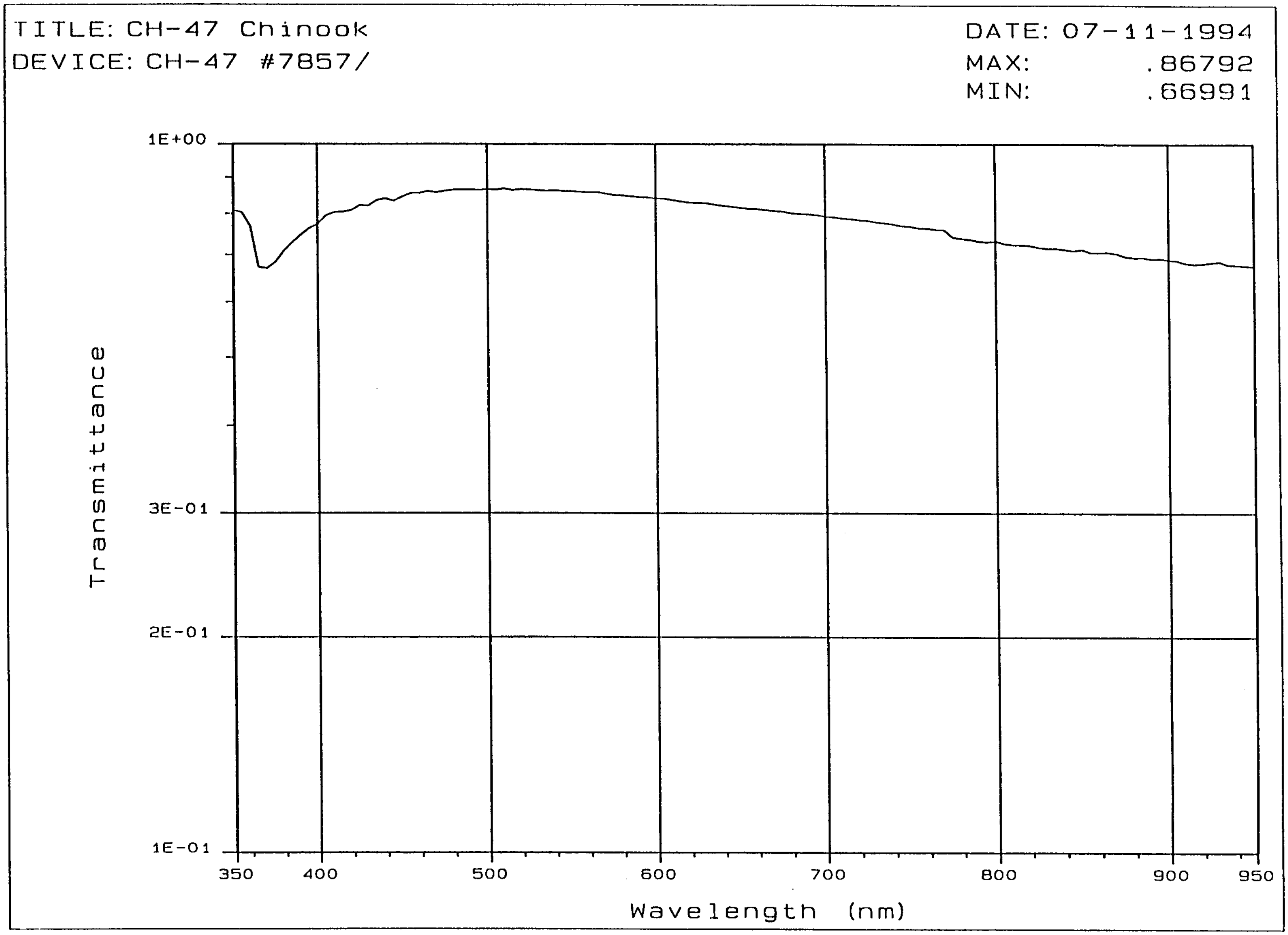

Figure 13. Spectral transmittance curve for CH-47D Chinook.

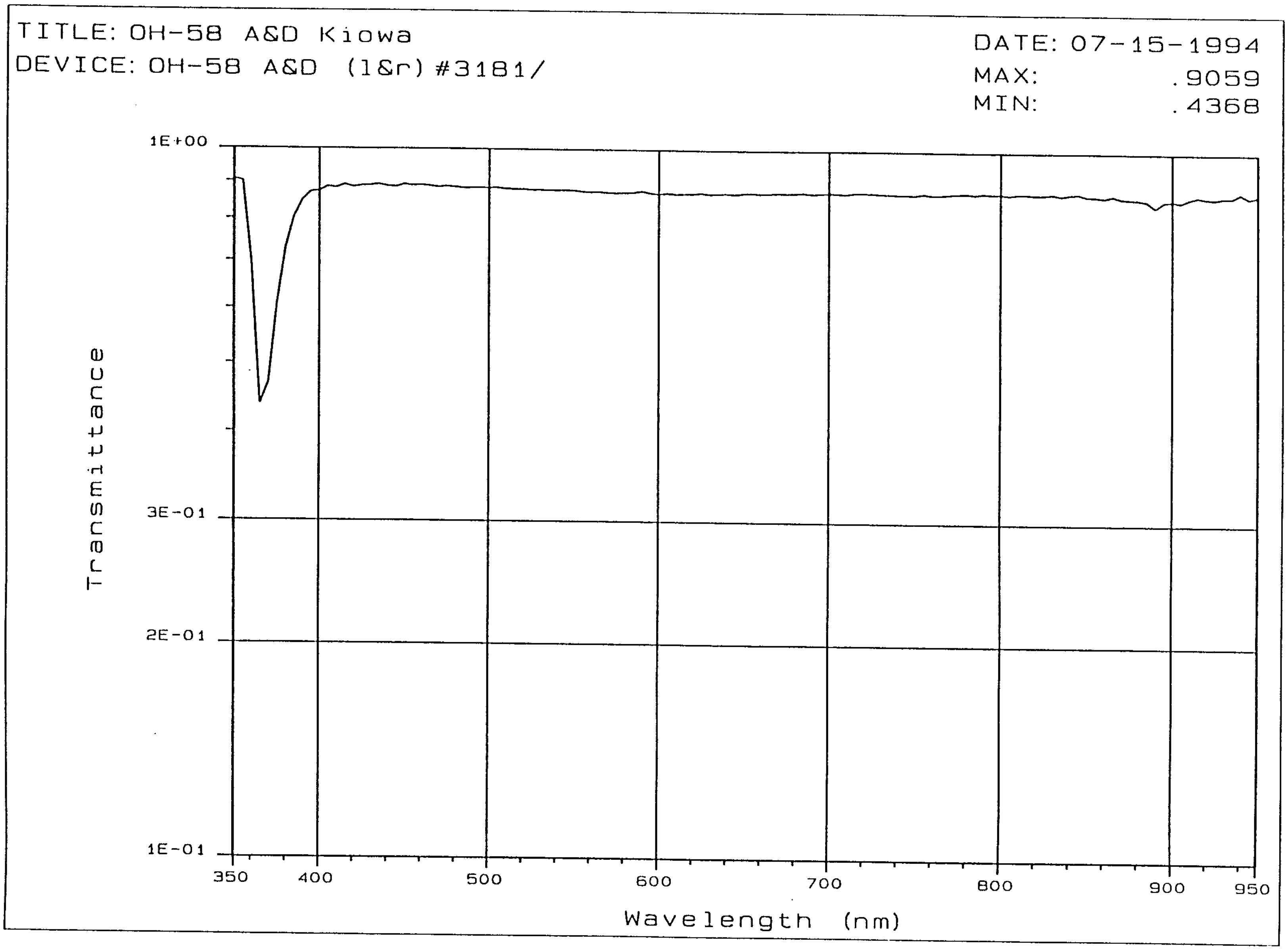

Figure 14. Spectral transmittance curve for OH-58A/D Kiowa.

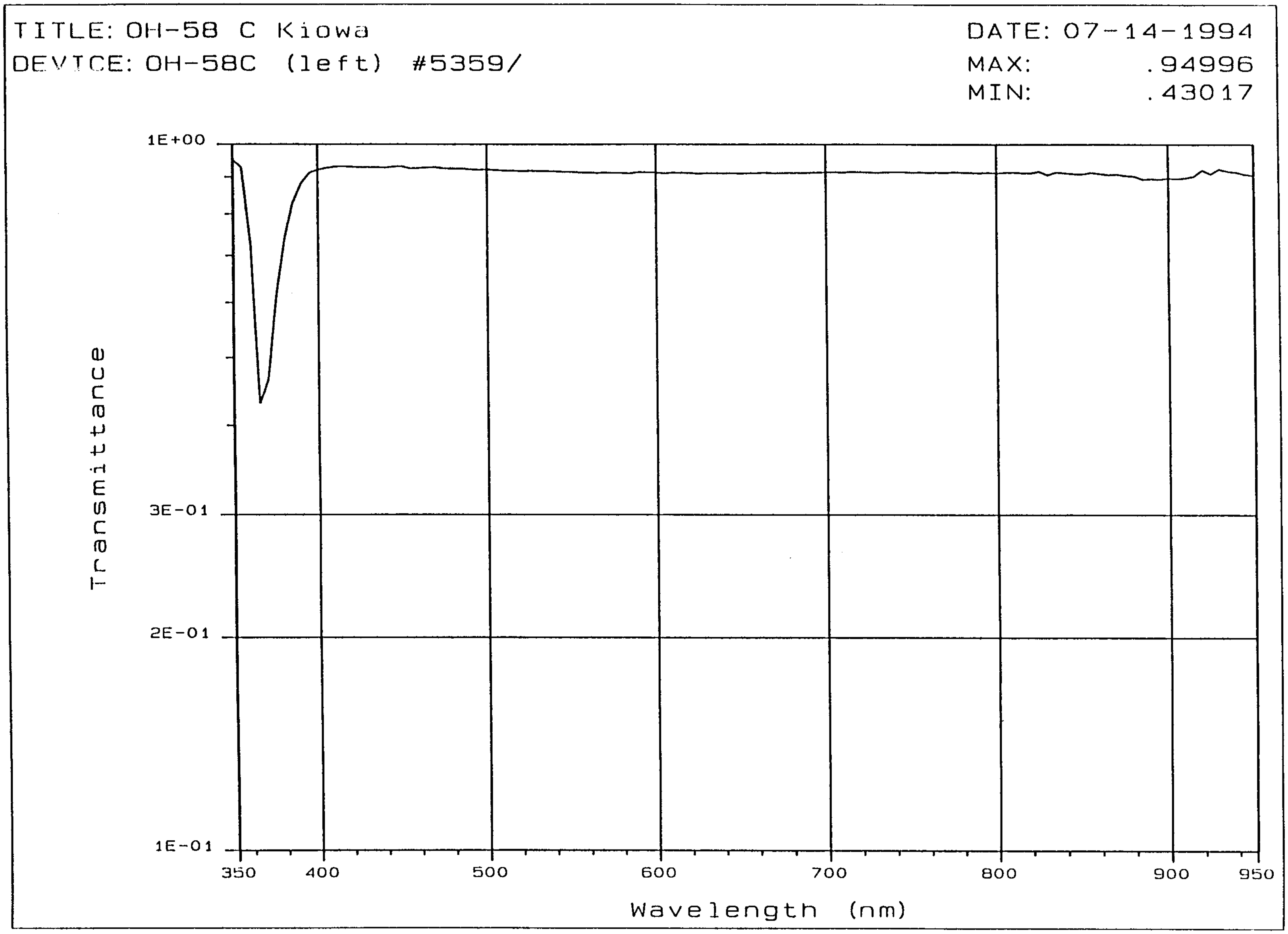

Figure 15. Spectral transmittance curve for OH-58C Kiowa.

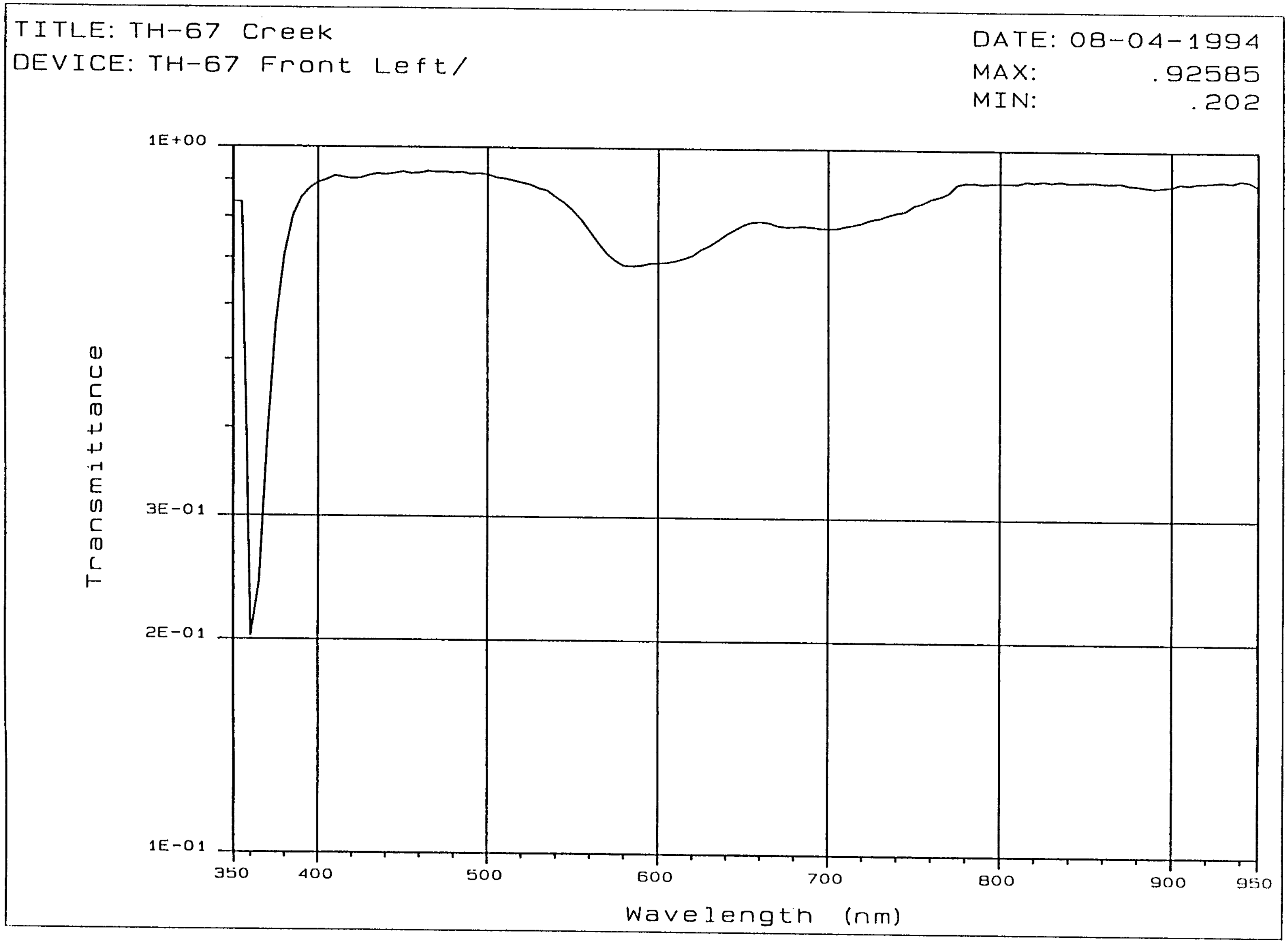

Figure 16. Spectral transmittance curve for TH-67 Creek.

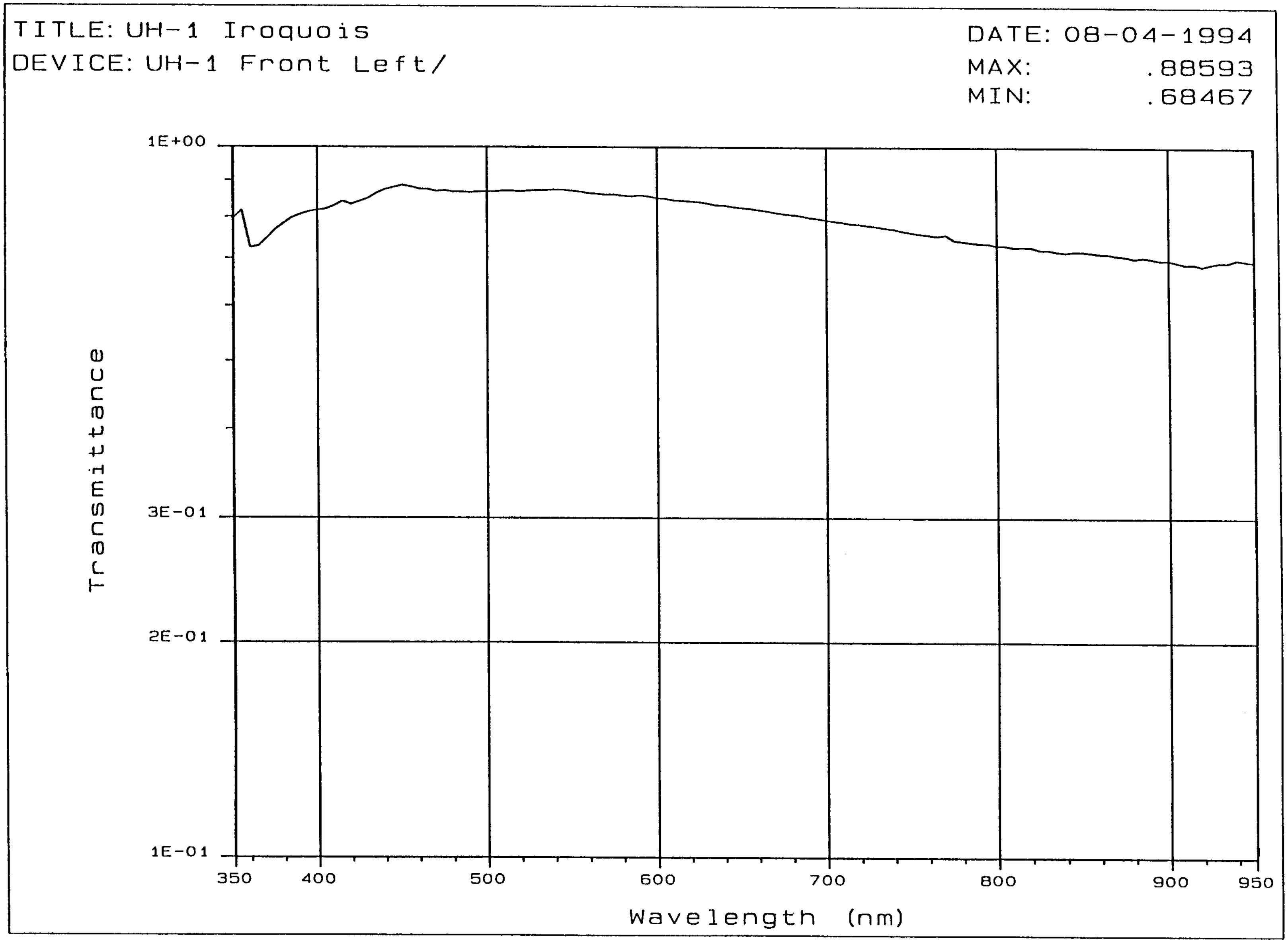

Figure 17. Spectral transmittance curve for UH-1 Iroquois.

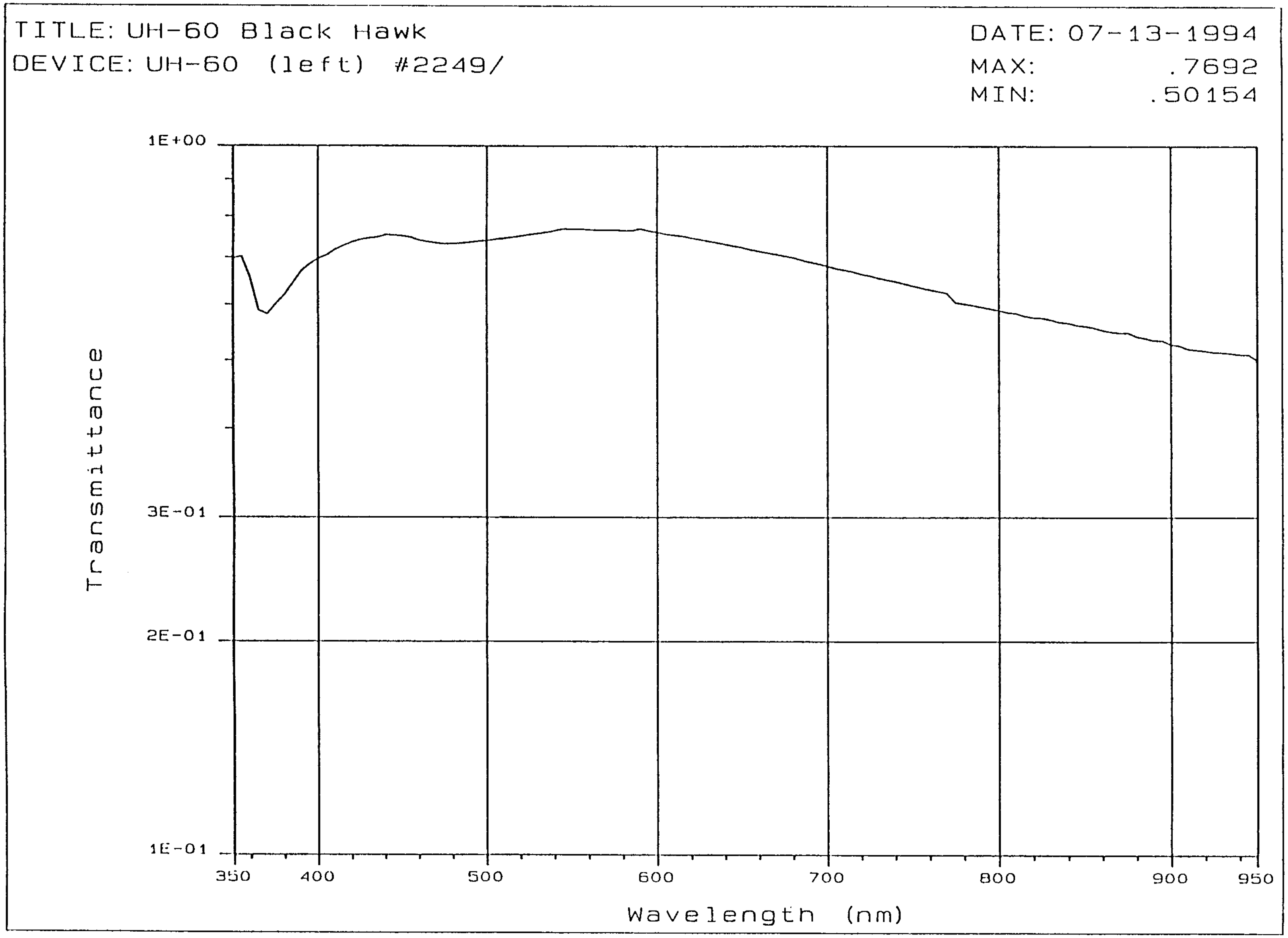

Figure 18. Spectral transmittance curve for UH-60 Black Hawk.

The spectral curves in Figures 11-18 correspond to the descriptions above. The curves for the AH-1, OH-58, and TH-67 samples demonstrate the spectral transmittance characteristics of acrylic materials. These include an ultraviolet cut-off between 350-380 nm and excellent spectral neutrality (flatness of transmittance) over the visible spectral range 400-780 nm. These acrylic windscreens also provide high, relatively flat, transmittance over the spectral response range of the ANVIS, 450-930 nm. The TH-67 sample has a deviation from neutrality over the range 560-780 nm (Figure 16). This decrease in transmittance of the red wavelengths produces the bluish color of the tint.

The glass samples of the AH-64, CH-47, UH-1, and UH-60 also provide a relatively neutral transmittance over the measured spectral range with a similar UV cutoff around 360 nm, but present some relative falloff in transmittance beyond 600 nm. This is of little significance to naked eye vision, which peaks at 550 nm. It also has little effect on ANVIS performance, which has enhanced sensitivity over the spectral range of 625-900 nm.

Note 1: The OH-6, while not available for laboratory measurement of spectral transmittance, is manufactured from acrylic material and should have optical characteristics similar to the AH-1, OH-58A, and TH-67 samples.

Note 2: The apparent increase of transmittance below 360 nm present in the curves is an artifact of the collection optics and spectral sensitivity of the spectroradiometer.

Luminous transmittance

Clear glass materials typically provide 80 to 92 percent photopic luminous transmittance; acrylic typically provides 85 to 92 percent (IES, 1984). The photopic and scotopic luminous values obtained in the laboratory measurements are presented in Table 1. The photopic values ranged from 73 to 93 percent; scotopic values ranged from 81 to 91 percent. When the TH-67 tinted samples are excluded, the photopic values for the glass samples ranged from 82 to 88 percent and the values for the acrylic samples ranged from 90 to 93 percent. The lowest photopic values, 73 and 77 percent, were for the tinted TH-67 samples.

The scotopic values generally tracked within a few percentage points of their corresponding photopic values. This was due to the flatness of the transmittance properties of glass and acrylic. The exception, as noted, of the TH-67 samples and their attenuation of red light produced higher scotopic values.

Based on the laboratory measurements, all of the tested windscreen samples met the requirements of MIL-W-81752A(AS).

The photopic luminous transmittance values obtained for flight line aircraft are presented in Table 2. These values ranged from 58 to 84 percent.

Table 1.

Luminous transmittance (in percent).

Aircraft	Panel position and FSN*		Photopic	Scotopic
AH-1	front	1560-01-028-0476	92	91
AH-64 AH-64 AH-64	forward center aft	1560-01-170-7475 1560-01-170-7474 1560-01-165-9621	82 82 88	81 81 89
CH-47 CH-47 CH-47	right center left	1560-00-133-7158 1560-00-113-7857 1560-00-133-7157	83 85 82	82 87 82
OH-6	left right	1560-00-133-6186 1560-00-133-6229	**	**
OH-58A OH-58A	right left	1560-00-127-3179 1560-00-127-3181	90 92	91 91
OH-58C OH-58C (curved)	right left	1560-01-070-5360 1560-01-070-5359	92 92	91 91
OH-58D OH-58D	right left	1560-00-127-3179 1560-00-127-3181	90 92	91 91
TH-67 TH-67	right left	206-031-115-105 206-031-115-0335	73 77	82 85
UH-1 UH-1	right left	1560-00-433-7271 1560-00-433-7321	89 93	89 89
UH-60 UH-60 UH-60	right center left	1560-01-084-2250 1560-01-207-7485 1560-01-084-2249	** 82 84	** 82 81

* Federal stock number; for TH-67, manufacturer part number is given.

** Samples of OH-6 and OH-58 flat windscreens and the right front UH-60 windscreen were not available.

Table 2.

Field measurements of photopic luminous transmittance (in percent).

Aircraft windscreen	Photopic transmittances (in percent)	Mean	Standard deviation
AH-1 front bottom	83, 75, 76, 81, 77, 82	79	3.4
AH-64 front bottom	71, 67, 76, 72, 73, 70	72	3.0
CH-47 front left	--, 62, 68, 70, 63, 48*	66	3.9
OH-6 front left	80, 70, 67, 70, 71, 75	72	4.6
OH-58A front left	77, 77, 75, 78, 76, 75	76	1.2
OH-58C curved front left	53, 62, 59, 58*	58	3.7
OH-58C flat front left	70, 60, 58, 63, 58, 66	63	4.8
OH-58D front left	71, 72, 73, 74, 70, 76	73	2.2
TH-67 front left	65, 64, 62, 64, 63, 67	64	1.7
UH-1 front left	83, 86, 84, 82, 84, 84	84	1.3
UH-60 front left	5, 75, 75, 71, 74, 75	74	1.6

* Note: For the CH-47, the first reading was invalid due to a recording error and for the last reading, condensation on the interior of windscreen produced an erroneous value; neither value is shown in the table. For the OH-58C with curved windscreen, only four aircraft were available for measurement. These windscreens exhibited significant levels of abrasion and the obtained values were further affected by condensation and fogging.

In Table 3, a comparison between the laboratory and field photopic luminous transmittance values (for front left windscreens) is presented. The percent decrease in photopic transmittance between the unused and fielded windscreens are presented in the last column. In each case, the field value decreased from the laboratory value. Percent decrease

Table 3.

Comparison of laboratory and field photopic luminous transmittance measurements.

Aircraft	Laboratory value	Field value	Percent decrease
AH-1	92	79	14
AH-64	82	72	12
CH-47	83	66	20
OH-6	--	72	--
OH-58A	92	76	17
OH-58C curved	92	58	37
OH-58C flat	--	63	--
OH-58D	92	73	21
TH-67	77	64	17
UH-1	93	84	10
UH-60	84	74	12

Note: Unused samples of OH-6 and OH-58C flat windscreens were not available.

ranged from 10 percent for the UH-1 to 37 percent for the OH-58C (curved). The mean percent decrease was 18 percent. (If the relatively large percent decrease value of 37 for the OH-58C is excluded, the mean percent decrease was 15 percent.) Several factors attributed to this decrease. As would be expected under field conditions, the windscreens were dirty both inside and outside. In addition, because the field measurements were taken at night, condensation and fogging also were present in varying degrees. These factors, while contributing, are considered secondary to the effects of haze resulting from the highly abraded external surfaces of the windscreens. Figure 19 shows an example of an AH-64 windscreen having a significant level of abrasion.

Summary

All of the windscreen samples (except for the tinted TH-67) were found to be spectrally neutral over the visible spectrum. Likewise, all samples indicated sufficient spectral transmittance over the spectral range required for optimal performance of ANVIS.

For luminous transmittance, all of the unused samples measured in the laboratory met the requirements of MIL-W-81752A(AS). However, an analysis of the field measurements of

Figure 19. Example of surface abrasion present in an AH-64 windscreen.

luminous transmittance, while qualified by the small sample size, shows significant decreases in transmittance for all windscreen types. These decreases are considered to be caused by haze resulting from the physical abuse to which the windscreens are subjected.

The governing specifications require attack aircraft to have an average luminous transmittance of not less than 80 percent and nonattack aircraft to have not less than 60 percent. All windscreen samples met this requirement in the laboratory measurements. However, based on field measurements, neither attack aircraft, the AH-1 or AH-64, met the 80 percent requirement. The OH-58C curved windscreens, with a mean value of 58 percent, failed to meet the 60 percent requirement for nonattack aircraft. The conclusion which can be drawn from this study seems to be that all windscreen samples meet the specification for luminous transmittance upon delivery, but during usage degrade in performance. Since data were not available to correlate performance degradation with length of service, it is not possible to formulate a recommendation on how often to replace the windscreens. However, it is obvious from the data that in the harsh environments of military flight, the optical performance of the windscreens does degrade below that required by the specification and this situation warrants a policy of closer inspection at the unit level.

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Department of Defense. 1988. Military specification: Windshield systems, fixed wing aircraft, general specification for. Washington, DC: Department of Defense. MIL-W-81752A(AS), Amendment 1.

Illuminating Engineering Society (IES) of North America. 1984. IES lighting handbook. J. E. Kaufman, editor. New York, NY: IES of North America.

Appendix A

List of transparency manufacturers.

AH-1

Bell Helicopter Textron, Inc.
600 E Hurst Blvd.
P.O. Box 482
Fort Worth, TX 76101-8020
(817)280-2011

LP Aero Plastics Inc.
Road 1
P.O. Box B
Jeannette, PA 15644-9730
(412)744-4448

AH-64

McDonald Douglas Helicopter Co.
Sub of McDonald Douglas Corp.
6775 Centinela Ave.
Culver City, CA 90230-6370
(310)305-6562

PPG
Aircraft Product Sales
1719 Highway 72E
P.O. Box 040004
Huntsville, AL 35804
(205)851-7001

CH-47

PPG
Aircraft Product Sales
1719 Highway 72E
P.O. Box 2200
Huntsville, AL 35804
(205)859-2500

Boeing Helicopter
Division of the Boeing Co.
Boeing Center
Industrial Hwy Bldg 3-25
Ridley Park, PA 19078
(215)591-3010

Appendix A (Continued)

List of transparency manufacturers

OH-6

McDonnell Douglas Helicopter Co.
6775 Centinela Ave.
Culver City, CA 90230-6370
(310)305-6562

Ten Cate Aerospace Inc.
5101 Blue Mound Rd.
Fort Worth, TX 76106

Texstar
802 Ave. J East
Grand Prairie, TX 75050-2552
(214)647-1366

OH-58

Bell Helicopter Textron Inc.
600 E Hurst Blvd.
P.O. Box 482
Fort Worth, TX 76101-8020
(817)280-2011

Texstar, Inc.
802 Ave. J East
Grand Prairie, TX 75050-2552
(214)647-1366

TH-67

Bell Helicopter Textron Inc.
600 E Hurst Blvd.
P.O. Box 482
Fort Worth, TX 76101-8020
(817)280-2011

UH-1

PPG Industries, Inc.
Aircraft Product Sales
1719 Highway 72 E
P.O. Box 040004
Huntsville, AL 35804
(205)851-7001

Appendix A (Continued)

List of transparency manufacturers

UH-60

PPG Industries, Inc.
1 PPG PL
Pittsburgh, PA 15272-0001
(412)434-3131

PPG
1719 Highway 72E
P.O. Box 2200
Huntsville, AL 35804
(205)859-8500

Davis Aircraft Product Co. Inc.
1150 Walnut Avenue
P.O. Box 525
Bohemia, NY 11716-2105
(516)563-1500

Appendix B

List of equipment manufacturers

EG&G Gamma Scientific Inc.
3777 Ruffin Rd.
San Diego, CA 92123

Minolta Corporation
101 Williams Drive
Ramsey, NJ 07446

Photo Research
Division of Kollmorgen
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P.O. Box 2192
Chatsworth, CA 91313-2192

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Army Audiology and Speech Center
Walter Reed Army Medical Center
Washington, DC 20307-5001

Commander/Director
U.S. Army Combat Surveillance
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ATTN: SFAE-IEW-JS
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